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Study of the Effects of Mechanical Damage on the Performance of Filament-Wound Motor Cases

PROGRESS REPORT NO. 1

1 APRIL THROUGH 31 MAY 1963

PREPARED UNDER NAVY BUREAU OF WEAPONS

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STUDY OF THE EFFECTS OF MECHANICAL DAMAGE ON THE PERFORMANCE OF FILAMENT-WOUND MOTOR CASES

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ABSTRACT

This interim technical progress report discusses the work performed under Navy Bureau of Weapons Contract NOw 63-0449-c (FBM) from 1 April through 31 May 1963. This report discusses the planning and organization of the fabrication and testing portions of the program and the results of preliminary testing.

The program plan as presented herein was prepared with the assistance and technical direction of Mr. J. A. Kies, and Dr. I. Wolock, of the Naval Research Laboratory and Mr. Harold Bernstein of the Special Projects Office. In the course of the program Mr. J. A. Kies and Dr. I. Wolock will serve as technical monitors.

The objectives of the study program under this contract are to study the effects of surface flaws on the performance of Polaris motor cases, to compare the effect of winding sequence on the ability to resist failure from surface flaws, and to determine the reliability of various repair techniques.

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SECTION I - INTRODUCTION

A. GENERAL

This report is the first in a series covering a study of vulnerability of filament-wound motor cases to mechanical damage. The program is divided into two parts: (1) the correlation of failure stress as a function of flaw depth in Polaris-type cases and (2) the determination of means of making repairs on damaged cases.

B. PART I - FAILURE STRESS AS A FUNCTION OF FLAW DEPTH

The first objective of this part of the program will be to determine by experimental tests what correlation can be realistically derived for failure stress as a function of flaw depth for motor cases of the thicknesses of Polaris A-3 first- and second-stage cases. The second objective of this part of the program is to determine the effect of winding sequence on the ability to resist failure from surface flaws. This will be accomplished by comparing the interspersing (or interleaving) method of applying longo and circo layers, employed on the second-stage motor case, with the sequential (all hoop layers on the outside) method, employed on the first-stage motor case, as to their relative ability to resist flaws of equal depth.

This information will be obtained through the pressure testing of 6-inch-diameter and 18-inch-diameter filament-wound pressure vessels that have been machine-flawed to prescribed depths.

C. PART II - REPAIRS ON DAMAGED CASES

The objective of this part of the program will be to determine means of making

repairs on damaged cases and to determine the reliability of and ease of performing various repair techniques. This information will be obtained through the repair of 18-inch-diameter bottles that have been flawed to a depth that, as determined from Part I, decreases their strength level by at least 25 percent.

SECTION II - PROGRESS COMMENTARY

A. GENERAL

The effort for this period consisted of planning and organizing the testing portion of the program. Inasmuch as specimen configuration and method of testing required definition, this period was concerned primarily with the final selection of test specimens to be fabricated and tested, the determination of testing procedures, and the procurement of materials.

B. DEFINITION OF TEST SPECIMENS

1. Six-Inch-Diameter Bottle

The six-inch-diameter bottle will be fabricated using the interspersing method of applying longo and circo layers. The total wall thickness of this bottle, which represents the second-stage Polaris case, will be 0.140 inch. The specimen will contain five polar-wrapped longo layers and seven hoop-wrapped circo layers. The following four flaw depths will be studied on this specimen (see Figure 1):

(1) A flaw through one circo layer
(2) A flaw through three circo layers
(3) A flaw through three circo layers and one longo layer
(4) A flaw through three circo layers, one longo layer, and one circo layer

2. Eighteen-Inch-Diameter Bottles

The 18-inch-diameter bottles will be fabricated using both the interspersing and sequential wrapping techniques. The total wall thickness of these bottles,

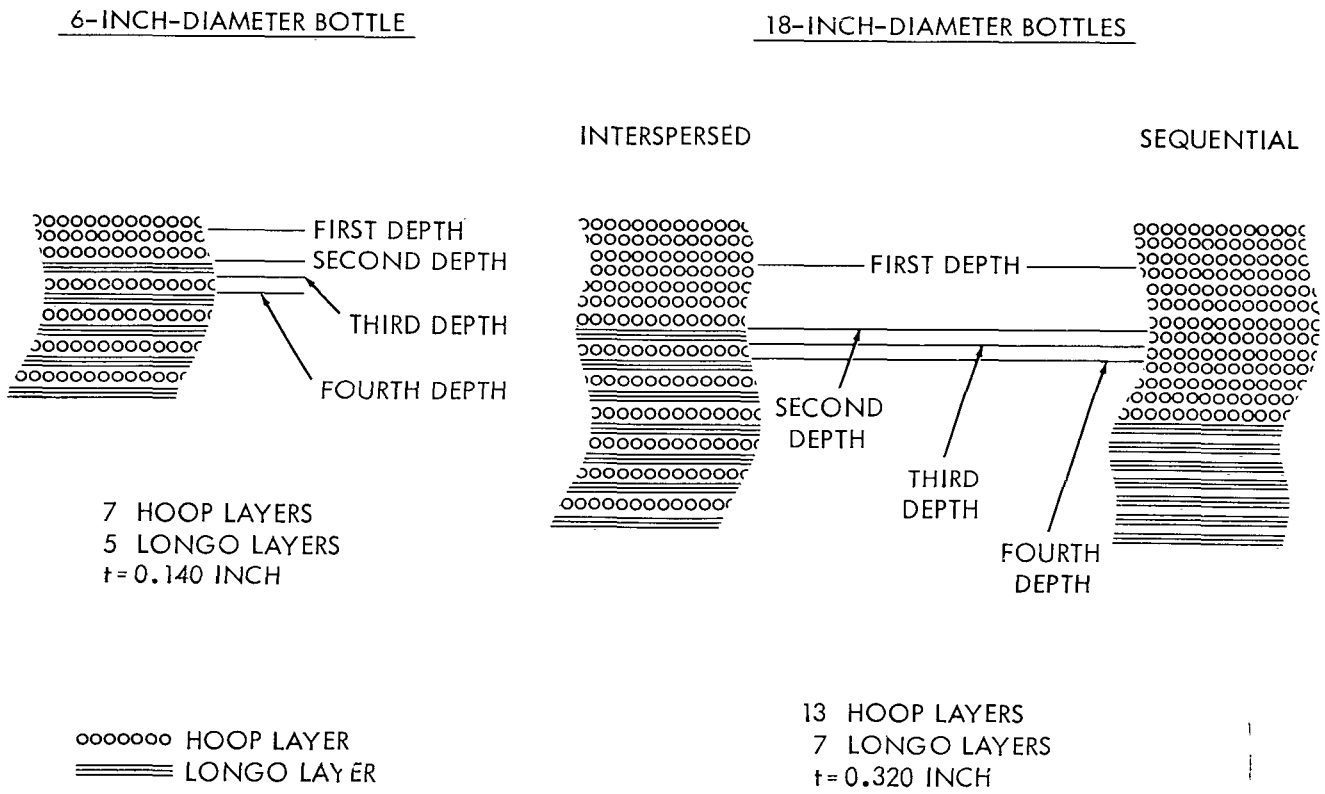


Figure 1. Flaw Depths

which represent the first-stage Polaris motor cases, will be 0.320 inch. The specimen will contain 7 polar-wrapped longo layers and 13 hoop-wrapped circo layers. The interspersed bottle will have seven longo layers and six circo layers interleaved and then seven circo layers on the outside. The sequential bottle will have 7 longo layers and then 13 circo layers on the outside. The following four flaw depths for the 18-inch-diameter bottles (see Figure 1) will be studied:

(1) A flaw through three circo layers
(2) A flaw through seven circo layers
(3) A flaw through eight layers
(4) A flaw through nine layers

The flaw depth of the bottles for the repair study will be the depth that reduces the bottle strength by a minimum of 25 percent.

C. METHOD OF SPECIMEN TESTING

The test program will begin with three specimens of each configuration being hydroproofed to 80 percent of the design burst and then hydroburst to give a reference strength. Each of the remaining specimens will be hydroproofed to 80 percent of the hydroburst pressures thus established. The specimens will then be machine-flawed using an ultrasonic cutting tool to the prescribed depths.

Following the machine flawing operation, each test bottle will be carefully examined and the flawed region will be analyzed to define the essential numerical coefficients necessary for calculation of the total driving force (K^2) to propagate the flaw in the hoop direction as given by Kies*. With this information recorded, hydroburst tests will be conducted on each test bottle, using

*Kies, J.A., Vulnerability of Filament-Wound Pressure Vessels to Mechanical Damage, Fourth Semiannual Polaris Glass-Reinforced Plastics Research and Development Conference, Sacramento, California, 23 January 1963.

the strain rate of 0.01 inch/inch/minute which has been standardized on the Polaris first-stage A-3 motor case. After 1000 psi has been reached at this rate, the pressure will be held for one minute and the specimen observed. Pressurization at the prescribed rate will continue for another 1000 psi, and then another one-minute hold will be observed. This procedure will be continued each 1000 psi until failure occurs. If during any of the hold periods failure appears imminent, the hold can be extended to three minutes. Photographs of each specimen will be taken at the beginning and end of each hold period.

D. MATERIAL PROCUREMENT

1. Composite Material

U.S. Polymeric E-787, S-HTS, 20-end, prepreg roving, Specification WS-1028A, has been purchased for the fabrication of the test specimens, and the first shipment of material has arrived.

2. Mandrels

Mandrels for the specimen fabrication have been ordered from the Goodyear Tire and Rubber Company (GT&R). The mandrels are of plaster construction sprayed with GT&R M-800 liner material. The first six-inch-diameter mandrels will be received during the week of 16 June 1963.

E. SPECIMEN DESIGN

1. General

The specimens of this program are designed to be similar to the construction and material of the Polaris A-3 first-stage and second-stage motor cases. U.S. Polymeric E-787 S-HTS prepreg roving material has been selected for all specimens.

2. Six-Inch-Diameter Bottle

The six-inch-diameter bottle (see Figure 2) will be fabricated with a total wall thickness of 0.140 inch, which is the wall thickness of the Polaris A-3 second-stage motor case. The design burst pressure of this bottle will be 7230 psi, which corresponds to a composite wall stress of 155,000 psi. The design specifications for the six-inch-diameter bottle are:

t_α = 0.055 inch

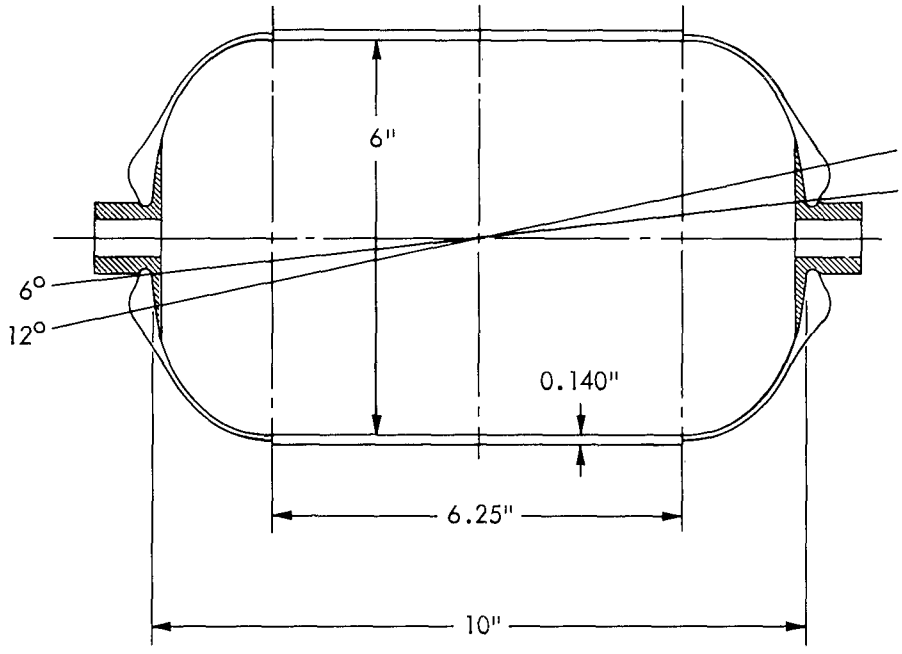
t_{90} = 0.085 inch

Winding sequence - 1 longo layer, $\alpha = 6^o$
1 hoop layer
1 longo layer, $\alpha = 7\text{-}1/2^o$
1 hoop layer
1 longo layer, $\alpha = 9^o$
1 hoop layer
1 longo layer, $\alpha = 10\text{-}1/2^o$
1 hoop layer
1 longo layer, $\alpha = 12^o$
3 hoop layers

NOTE: One longo layer is a 360-degree circuit. One hoop layer is a complete reverse wind.

3. Eighteen-Inch-Diameter Bottles

The 18-inch-diameter bottles (see figure 3) will be fabricated with a total wall thickness of 0.320 inch, which is the wall thickness of the Polaris A-3 first-stage motor case. The design burst pressure of this bottle will be 5050 psi, which corresponds to a composite wall stress of 142,000 psi. The design



5 LONGO LAYERS
7 HOOP LAYERS

Figure 2. Design of Six-Inch-Diameter Bottle

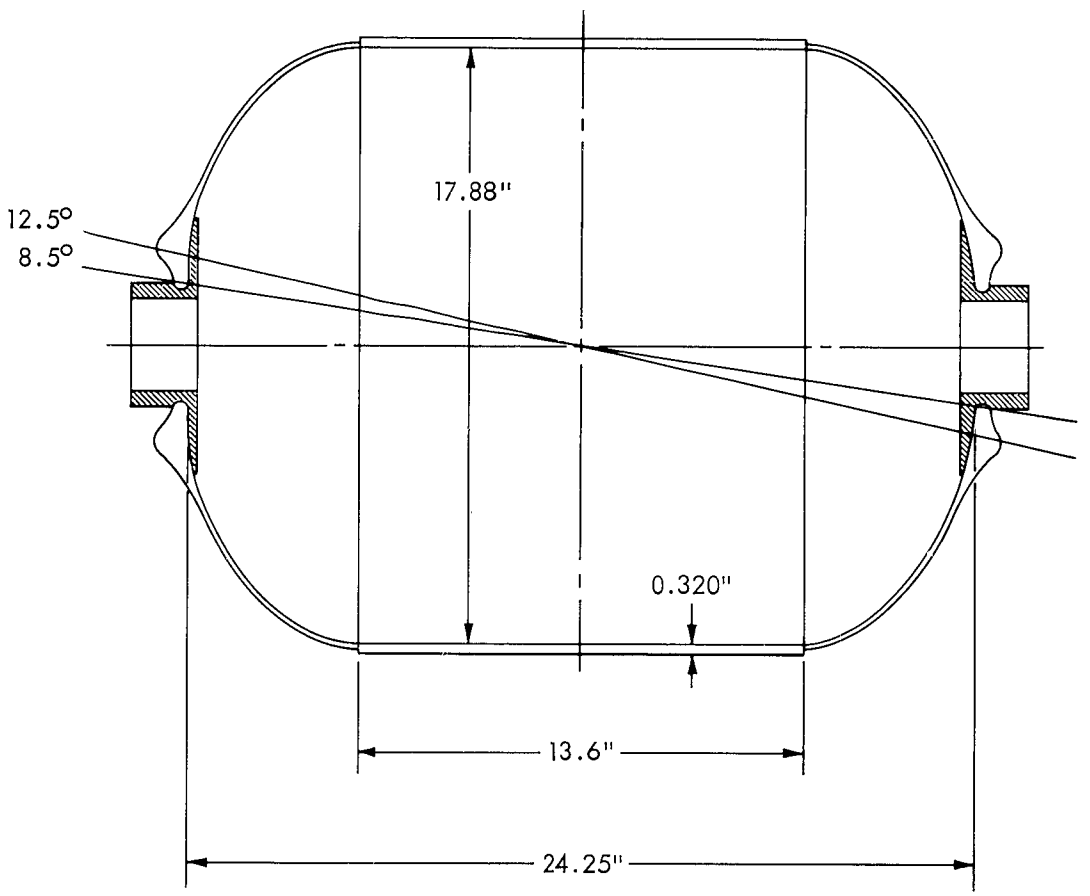


Figure 3. Design of 18-Inch-Diameter Bottle

specifications for the 18-inch-diameter bottle are:

t_α = 0.120 inch

t_{90} = 0.200 inch

Winding Sequence - Sequential Bottle

7 longo layers, α = 8-1/2 to 12-1/2°
13 hoop layers

Winding Sequence - Interspersed Bottle

1 longo layer, α = 8-1/2°
1 hoop layer
1 longo layer, α = 9°
1 hoop layer
1 longo layer, α = 10°
1 hoop layer
1 longo layer, α = 10-1/2°
1 hoop layer
1 longo layer, α = 11°
1 hoop layer
1 longo layer, α = 12°
1 hoop layer
1 longo layer, α = 12-1/2°
7 hoop layers

The 18-inch-diameter bottles that will be used for the study of the repair of flaws are to be of the same construction as one of the above. The repair techniques to be studied are as follows:

(1) Remove the cut fibers and replace them with an equal amount of additional hoop windings.

(2) Add additional hoop windings to the flawed area without any removal of cut filaments.

(3) Bond a fiberglass patch to the flawed area with a room temperature curing resin.

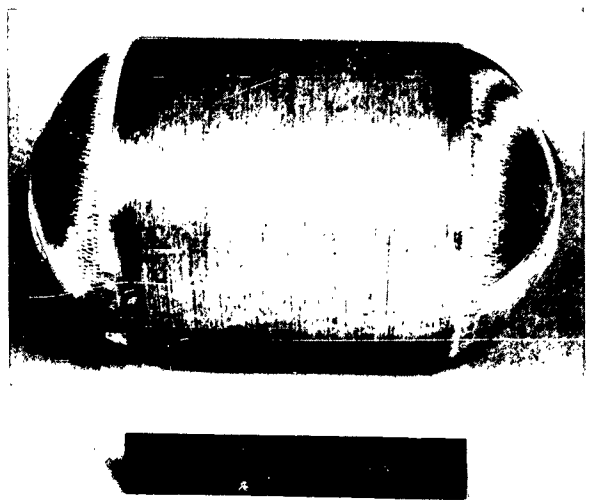
(4) Bond a fiberglass patch to the flawed area with an elevated temperature curing resin.

Prior to the actual beginning of this portion of the program, a review of all repair attempts by various Polaris case manufacturers will be made, and a final decision will be made with the Special Projects Office to determine the repair techniques to be considered.

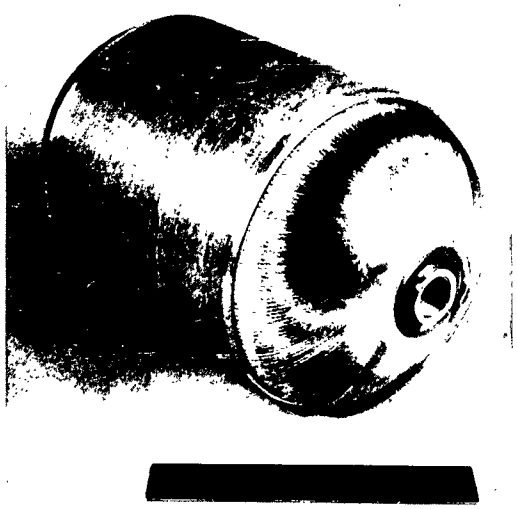
F. PRELIMINARY TESTING

To finalize the bottle configuration and the fabrication techniques, preliminary tests have been conducted on six-inch-diameter test bottles. The increased thickness of this specimen over the standard GAC six-inch-diameter test bottle used for the screening of materials necessitates the incorporation of certain design and fabrication modifications. The first preliminary bottle tested was fabricated similarly to the standard bottle with the longitudinal winding angle maintained at 6 degrees for each of the four longo layers. Three hoop layers were interspersed with these layers, and three additional hoop layers were placed on the outside. Due to the buildup around the hub, a great deal of bridging occurred in the area adjacent to the hub for the second, third, and fourth longo wraps. When pressurized, this specimen failed at 5100 psi with failure occuring by the blowing out of the dome fitting.

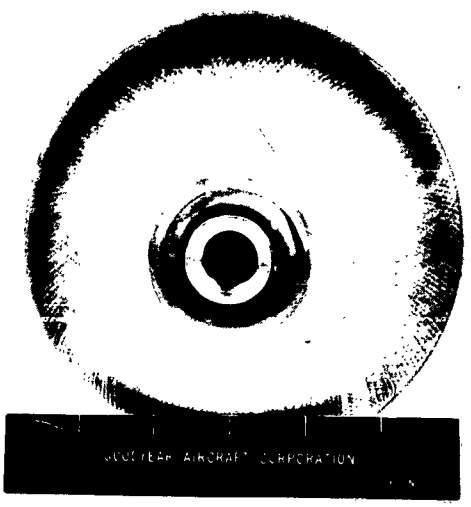
This problem of bridging around the dome fitting can be alleviated by three methods. One method is to vacuum-bag the domes to achieve better compaction, which has proven quite successful on the Polaris A-3 first-stage motor case. The second method would be to add reinforcing doilies around the hub between longo layers to act as filler material and give added strength. The third and simplest method is to vary the longitudinal winding angle so that the large buildup around the hub does not take place, and each additional longitudinal layer attempts to cinch down the previous layer. The third method was attempted in the second preliminary bottle fabricated. Figure 4 shows the results obtained with this method of fabrication. When pressurized, this specimen failed at 7250 psi, which is above the design burst pressure; however,



SIDE VIEW



THREE-QUARTER VIEW



END VIEW

Figure 4 - Views of Heavy-Wall Six-Inch-Diameter Pressure Test Vessel

failure again occurred in the dome. The wall thickness of the cylinder of this specimen was 0.156 inch instead of the desired 0.140-inch wall thickness. The extra thickness was due to the use of an extra hoop layer instead of seven as indicated in paragraph E-2. The removal of this extra hoop layer in the cylinder will provide a hoop failure without a significant loss in burst pressure. This method of fabrication will therefore be used in the program.

SECTION III - WORK PLAN FOR NEXT PERIOD

During the next reporting period all of the six-inch-diameter mandrels and the first of the 18-inch-diameter mandrels will be received. The fabrication of the six-inch-diameter bottles will be completed, and the flawing and testing of these bottles will be started.

An investigation into repair techniques that have been attempted by Polaris motor case fabricators will be undertaken during this period, and the study and design of the repair methods to be used on this program will begin.

SECTION IV - SUMMARY

Work is progressing satisfactorily on the proposed program. With the definition of specimen configurations and testing procedures made during this period, it is anticipated that the program will proceed as projected in Figure 5.

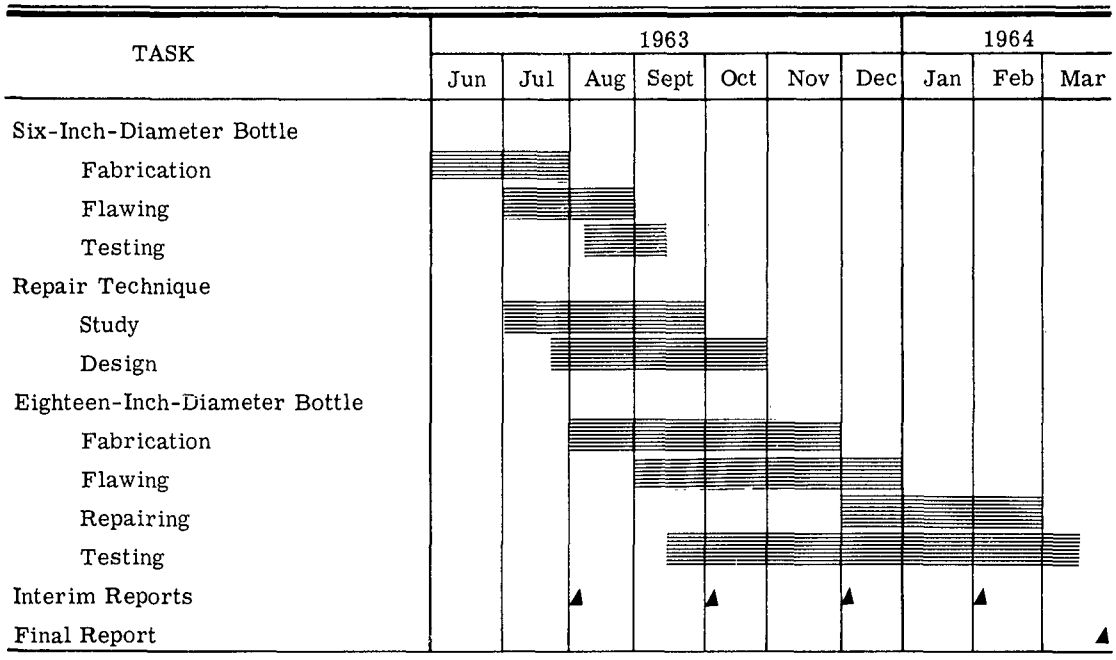


Figure 5. Program Schedule

21 June 1963

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NOTICE

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Any questions regarding content should be directed to Goodyear Aircraft Corporation.

H.R. Martin
Contract Administrator